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Impact analysis of biodiesel on engine performance—A review

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ABSTRACT

Energy is a basic requirement for economic development. Every sector of Indian economy-agriculture, industry transport, commercial and domestic needs input of energy. The economic development plans implemented since independence have necessarily required increasing amount of energy. As a result consumption of energy in all forms has been steadily rising all over the country. This growing consumption of energy has also resulted in the country becoming increasingly dependent on fossil fuels such as coal, oil and gas. Rising prices of oil and gas and potential shortage in future lead to concern about the security of energy supply needed to sustain our economic growth. Increased use of fossil fuels also causes environmental problems both locally and globally. In view of the fast depletion of fossil fuel, the search for alternative fuels has become inevitable, looking at huge demand of diesel for transportation sector, captive power generation and agricultural sector, the biodiesel is being viewed a substitute of diesel. The vegetable oils, fats, grease are the source of feed stocks for the production of biodiesel. Biodiesel is an engine fuel that is created by chemically reacting fatty acids and alcohol. This usually means combining vegetable oil with methanol in the presence of a catalyst (usually sodium hydroxide). Biodiesel is much more suitable for use as an engine fuel than straight vegetable oil for a number of reasons, the most notable one being its lower viscosity. The aim of the present paper is to focus on the work done in the area of biodiesel and also the impact analysis of biodiesel on engine performance.

Contents

1. Introduction

1.1. A global renaissance in energy production

The availability and environmental impact of energy resource will play a critical role in the progress of the world's societies and

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the physical future of our planet. The majority of human energy needs are currently met using petrochemical sources, coal and natural gases but these fossil fuels are approaching depletion and their continued use has had damaging environmental consequences. Worldwide energy consumption has increased more than twenty fold in the last century and with the exception of hydroelectricity and nuclear fusion energy, all current major energy sources are finite. At present uses rates, these sources will soon be exhausted [1] and this has contributed to soaring fossil fuel prices. As the demand of energy has grown, so have the adverse environmental effects of its production. Emission of CO_2, SO_2, NO_x from fossil fuel combustion are the primary causes of atmospheric pollution [2]. The accumulation of carbon dioxide and other greenhouse gases in the atmosphere is thought to be responsible for climate change, which is predicted to have disastrous global consequences for life on this planet [3].

Renewable energy sources are indigenous, and can therefore contribute to reducing dependency on oil imports and increasing security of supply. The bio fuel policy aims to promote the use in transport of fuels made from biomass, as well as other renewable fuels. Bio fuels provide the prospect of new economic opportunities for people in rural areas in oil importer and developing countries. The central policy of bio fuel concerns job creation, greater efficiency in the business environment, and protection of the environment [4]. Bio fuel – liquid or gaseous fuels derived predominantly from biomass – may be able to provide an alternative source of energy that is both sustainable and without serious environmental impact. Bio fuel is produced from plant oils, sugar beets, cereals, organic waste and processing of biomass.

1.2. India's scenario

India ranks sixth in the world in terms of energy demand accounting for 3.5% of world commercial energy demand in 2001. During 2004–2005, the country imported 95.86 million tons (MT) of crude oil valued at 26 billion U.S dollar. The Indian economy is expected to grow at the rate of more than 6% per annum which will necessitate energy demand to rise to 166 MT by 2019 and 622 MT by 2047. Currently, 70% of the fossil fuel requirements are imported placing a heavy burden on country's balance of payments (see Table 1).

The continuous increase of crude oil price together with the ambiguity in price trends caused by the limited crude oil production has forced India to consider biodiesel as an alternative. Biodiesel from jatropha and pongamia, assume significance and are considered best considered best option to substitute petroleum fuel there by reducing the dependence on imported oil. In addition to provide energy security and a decreased dependence on oil imports, biodiesel offer several other significant benefits such as reduced GHG emission, good fuel properties for vehicles, increased employment in the agricultural sector and conversion of wasteland into productive land.

1.2.1. National biodiesel mission

The demand for diesel is five times higher than the demand for petrol in India. But while the ethanol industry is established; the biodiesel industry is still in its infancy. India's current biodiesel choice of technology is the transerification of vegetable oils. The Government formulated an ambitious National Biodiesel mission to meet 20% of the country's diesel requirements by 2011–2012. Since the demand for edible vegetable oil exceeds supply, the government has decided to use non-edible oil from jatropha curcas seeds as biodiesel feedstock. The National Biodiesel Mission will be implemented in two stages.

A demonstration project carried out over the period 2003–2007 aimed at cultivating 400,000 ha of jatropha to yield about 3.75 tons oilseed per hectare annually. This phase was aimed to lay the foundation for a fast growing and self sustaining people and enterprise-driven programme of biodiesel production in the country and to produce enough seeds for the production of biodiesel. The project will also demonstrate the feasibility of other aspects like plantation area coverage, nurseries development, transesterification plant, blending and marketing, seed collection and oil extraction and financial requirements. The second phase which constitutes a commercialization period during 2007–2012 will continue jatropha cultivation and install more transesterification plants which will position India to meet 20% of its diesel need through biodiesel. The phase also plans to accomplish this through accelerating the momentum achieved in the demonstration project, converting plantation into a mass movement throughout the country. The success of this phase is expected to stimulate all stake holders and participants to muster resources with the government as prime mover.

1.3. Biodiesel

The best way to use vegetable oil as fuel is to convert it into biodiesel. Biodiesel is the name of a clean burning mono-alkyl ester-based oxygenated fuel made from natural, renewable sources such as new/used vegetable oils and animal fats. The resulting biodiesel is quite similar to conventional diesel in its main characteristics. Biodiesel contains no petroleum products, but it is compatible with conventional diesel and can be blended in any proportion with mineral diesel to create a stable biodiesel blend. The level of blending with petroleum diesel is referred as B*xx*, where *xx* indicates the amount of biodiesel in the blend (i.e. B10 blend is 10% biodiesel and 90% diesel). It can be used in CI engine with no major modification in the engine hardware.

1.4. Factor affecting engine performance using biodiesel

The following factors are considered by using biodiesel as engine fuel is

1.4.1. Engine power

Engine power and torque tend to be 3–5% lower when using biodiesel. This is due to the fact that biodiesel fuel has less energy per unit volume than traditional diesel fuel.

1.4.2. Fuel efficiency

Fuel efficiency tends to be slightly lower when using biodiesel due to the lower energy content of the fuel. Typically, the drop-off is in the same range as the reduction in peak engine power (3–5%).

1.4.3. Engine wear

Short-term engine wear when using biodiesel has been measured to be less than that of petroleum diesel. Engines are expected to experience less wear in the long run when using biodiesel.

1.4.4. Deposits and clogging

Deposits and clogging due to biodiesel have been widely reported but are generally traceable to biodiesel that is either of low quality or has become oxidized. If fuel quality is high, deposits in the engine should not normally be a problem.

1.4.5. Pollution from engine exhaust

Biodiesel results in much less air pollution due to its higher oxygen content and lack of both "aromatic compounds" and sulphur. The one exception to this is nitrogen oxide (NO_x) emissions, which tend to be slightly higher when using biodiesel. Proper tuning of the engine can minimize this problem.

Table 1
Biodiesel demand in India.

Year	Diesel demand (MT)	5% blend (MT)	Area (Mha)	20% blend (MT)	Area (Mha)
2006–2007	52.33	2.62	4.38	10.47	8.76
2011–2012	66.40	3.35	5.58	13.38	11.19

1.4.6. Cold-weather performance

Similar to petroleum diesel, engines tested in cold weather typically experience significant problems with operation caused primarily by clogging of the filters and/or choking of the injectors. The use of flow improving additives and "winter blends" of biodiesel and kerosene has proved effective at extending the range of operating temperatures for biodiesel fuel. Pure biodiesel tends to operate well at temperatures down to about 5 °C (this varies noticeably depending on the type of oil used). Additives typically reduce that range by about 5–8°, while winter blends have proved effective at temperatures as low as −20 °C and below.

2. Literature review

The increasing industrialization and modernization of the world has to a steep rise for the demand of petroleum products. Economic development in developing countries has led to huge increase in the energy demand. In India, the energy demand is increasing at a rate of 6.5% per annum. The crude oil demand of the country is met by import of about 80%. Thus the energy security has become a key issue for the nation as a whole. Petroleum-based fuels are limited. The finite reserves are highly concentrated in certain regions of the world. Therefore, those countries not having these reserves are facing foreign exchange crises, mainly due to the import of crude oil. Hence it is necessary to look forward for alternative fuels, which can be produced from feed stocks available within the country. Biodiesel, an ecofriendly and renewable fuel substitute for diesel has been getting the attention of researchers/scientists of all over the world. Biodiesel is an alternative fuel consisting of the alkyl monoesters of fatty acids from vegetable oils or animal fats one drawback of biodiesel is that it is more prone to oxidation than petroleum-based diesel fuel. In its advanced stages, this oxidation can cause the fuel to become acidic and to form insoluble gums and sediments. Monyem and Gerpen [1] evaluate the impact of oxidized biodiesel on engine performance and emissions. The engine performance of the neat biodiesels and their blends was similar to that of other engine having diesel fuel with the same thermal efficiency, but higher fuel consumption. Compared with unoxidized biodiesel, oxidized neat biodiesel produced 15 and 16% lower exhaust carbon monoxide and hydrocarbons, respectively. Tormos et al. [2], in their research, an experimental investigation has been performed to give insight into the potential of biodiesel as an alternative fuel for High Speed Direct Injection (HSDI) diesel engines. In their experiment they compare the combustion characteristics of diesel and biodiesel fuels in a wide range of engine loads. Nabi et al. [3] have made biodiesel from cotton seed oil. The result of the experiment is that the exhaust emissions including carbon monoxide (CO) particulate matter (PM) and smoke emissions were reduced. However, a slight increase in oxides of nitrogen (NO_x) emission was experienced for biodiesel. Lapuerta [4] studied, effect of biodiesel fuels on diesel engine emissions which show that the emission from biodiesel engine is less than diesel engine. Roskilly et al. [5] performed the experiment of testing of two small marine craft diesel engines fuelled with biodiesel. The test results show that the power output for both trial engines operating with biodiesel were comparable to that fuelled with fossil diesel, but with an increase in fuel consumptions. Zheng [6] checks the biodiesel engine performance and emissions in low temperature combustion. The research shows that simultaneous reductions of NO_x and soot emissions in modern production diesel engines when biodiesel is applied. Luján et al. [7] perform a comparative analysis of a DI diesel engine fuelled with biodiesel blends during the European MVEG-A cycle. Chen et al. [9] has done an experimental investigation to evaluate the effects of using methanol as additive to biodiesel–diesel blends on the engine performance, emissions and combustion characteristics of a direct injection diesel engine under variable operating conditions. Aydin and Ilkılıc [11] have performed an experiment and study the effect of ethanol blending with biodiesel on engine performance and exhaust emissions in a CI engine. Cheng and Cheung [12] compare the emissions of a direct injection diesel engine operating on biodiesel with emulsified and fumigated methanol. From the experiment it is found that an extra fuel injection control system is required, and there is also an increase in CO, HC and NO_2 (nitrogen dioxide) and particulate emissions in the engine exhaust, which are disadvantages compared with the blended mode.

Lee et al. [14] have studied the effects of B_{20} fuel and catalyst entrance section length on the performance of UREA SCR in a light-duty diesel engine. Rao [15] have performed the evaluation of DI with Jatropha Oil based Biodiesel. Biodiesel operation with supercharging was the best technique resulting in a specific fuel consumption of 0.3125 kg/kWh and exhaust smoke density of 22 HSU. Buyukkaya [16] has studied the effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics. The combustion characteristics of rapeseed oil and its diesel blends closely followed those of standard diesel. Kegl [17] studied the use of biodiesel at low temperature. Lina [18] have performed the test of characterization of particle size distribution from diesel engines fuelled with palm-biodiesel blends and paraffinic fuel blends. And it is found that energy efficiency also increases significantly by 12.3–15.1% with the introduction of paraffinic fuel blends into the engine. Fontaras [19] performed a experimental analysis to study the effects of low concentration biodiesel blend application on modern passenger cars. Balat [20] and Demirbas [21] have studied about progress and recent trends in biodiesel which show that modern diesel engines have fuel-injection system that is sensitive to viscosity change. Biodiesel seems to be a realistic fuel for future; it has become more attractive recently because of its environmental benefits. Biodiesel is an environmentally friendly fuel that can be used in any diesel engine without modification. The use of biodiesel is rapidly expanding around the world [22]. Because its physical properties and chemical composition are distinctly different from conventional diesel fuel, biodiesel can alter the fuel injection and ignition processes whether neat or in blends. The goal of creating chemical kinetic mechanisms for biodiesel, which will aid in the development of clean and efficient combustors that utilize alternative fuels [23]. The smaller molecules like methyl butanote are investigated the role of the characteristic ester group that is present in the fatty acid alkyl ester group that comprise biodiesel. Valente [26] perform experiment analysis of fuel consumption and emissions from a diesel power generator fuelled with castor oil and soybean biodiesel. Specific fuel consumption (SFC) and the exhaust concentrations of carbon dioxide (CO_2), carbon monoxide (CO), and hydrocarbons (HC) were evaluated. The results of this experiment are at low and moderate loads, CO emission was increased by nearly 40% and over 80% when fuel blends containing 35% of castor oil biodiesel or soybean biodiesel were used, respectively, in comparison with diesel oil. Coronado [28] determines the ecological efficiency in internal combustion engines by

the use of biodiesel. The result of the experiment is biodiesel have its complete life cycle and the closed carbon cycle (photosynthesis) was considered. Finally, the ecological efficiency for conventional diesel, when used in engines, is 77.34%; for gasoline, it is 82.52%, and for natural gas, it is 91.95% [29]. Ethanol blended biodiesel is totally a renewable, viable alternative fuel for improved cold flow behaviour and better emission characteristics without affecting the engine performance [10,24,25,30]. Compared with conventional diesel fuel, diesel–biodiesel blends showed lower carbon monoxide (CO), and smoke emissions but higher oxides of nitrogen (NO_x) emission. Agarwal et al. [31] has done an experimental investigation of control of NO_x emissions in biodiesel-fuelled compression ignition engine. Biodiesel-fuelled engines produce less carbon monoxide (CO), unburned hydrocarbon (HC), and particulate emissions compared to mineral diesel fuel but higher NO_x emissions. Lapuerta [32] have check the performance and emission of diesel engine by using waste cooking oil biodiesel. These biodiesel fuels were tested pure and blended (30% and 70% biodiesel content, volume basis) with a diesel reference fuel, on a common-rail injection diesel engine. Pure biodiesel fuels, compared to the reference fuel, resulted in a slight increase in fuel consumption, in very slight differences in NO_x emissions, and in sharp reductions in total hydrocarbon emissions, smoke opacity and particle emissions (in both mass and number), despite the increasing volatile organic fraction of the particulate matter. Murillo [34] checks the performance and emission of outboard diesel engine by using biodiesel. The results proved that biodiesel alone or blended biodiesel can be used in compression ignition outboard engines, thereby providing a viable alternative to diesel. Baldassarria [36] studied the chemical and toxicological characteristics of emissions from an urban bus engine fuelled with diesel and biodiesel blend. The use of biodiesel blend seems to result in small reductions of emissions of most of the aromatic and polyaromatic compounds. Kalligeros [38] check the performance of stationery diesel engine by taking two types of biodiesel, at proportions up to 50%. The two types of biodiesel appeared to have equal performance, and irrespective of the raw material used for their production, their addition to the marine diesel fuel improved the particulate matter, unburned hydrocarbons, nitrogen oxide and carbon monoxide emissions. Various researcher have checked the performance and emission characteristics of a CI engine fuelled with diesel–biodiesel–bio ethanol blends [25,35,37,39,40]. Engines' performances were evaluated by determining the brake specific fuel consumption and brake thermal efficiency. No [41] state that biodiesel generally causes an increase in NO_x emission and a decrease in HC, CO and PM emissions compared to diesel. It was reported that a diesel engine without any modification would run successfully on a blend of 20% vegetable oil and 80% diesel fuel without damage to engine parts. Shehata and Abdel Razek [42] perform a experimental study has been carried out to investigate performance parameters, emissions, cylinder pressure, exhaust gas temperature ($T_{exhaust}$) and engine wall temperatures (T_{wall}) for direct injection diesel engine. Ozsezen and Canakci [43] evaluated the performance, combustion and injection characteristics of a direct injection diesel engine when it was fuelled with canola oil methyl ester (COME) and waste (frying) palm oil methyl ester (WPOME). Aliyu et al. [44] studied the performance of a 4 stroke 3 cylinder direct injection naturally aspirated, Perkins D3.142 engine was measured in order to determine the suitability of a bio fuel produced from the seeds of Croton megalocarpus for engine use. The exhaust gas temperature increased with increase in load for all tested fuels. It was found that the performance of the CME was comparable to pure diesel fuel but the biodiesel produced lower smoke and NO_x emissions. Karthikeyan et al. [45], the purpose of his present study is to investigate the effect of thermal insulation on ethanol fuelled compression ignition engine. Highest brake thermal efficiency of 32% was obtained with ethanol fuel by insulating the combustion chamber. Emissions of the unburnt hydrocarbons, oxides of nitrogen and carbon monoxides were higher than that of diesel. But the smoke intensity and was less than that of diesel engine. Volumetric efficiency of the engine was reduced by a maximum of 9% in LHR mode of operation. Enweremadu et al. [46] studied the Overall, the engine performance of the UCO biodiesel and its blends was only marginally poorer compared to diesel. There were no noticeable differences between UCO biodiesel and fresh oil biodiesel as their engine performances, combustion and emissions characteristics bear a close resemblance. Sun et al. [47] studied the NO_x formation mechanisms are complex and affected by several different features (e.g., size, operating points, combustion chamber design, fuel system design, and air system design) of internal combustion engines. He et al. [48] an experimental study has been carried out on a direct-injection turbocharged diesel engine. The analysis showed that there was a close correlation between total PAHs emissions and particulate matter (PM) emissions for three fuels. Furthermore, the correlation became more significant when using biodiesel.

Gumus and Kasifoglu [49] In their study, apricot (Prunus armeniaca) seed kernel oil was transesterified with methanol using potassium hydroxide as catalyst to obtain apricot seed kernel oil methyl ester. Lower concentration of apricot seed kernel oil methyl ester in blends gives a better improvement in the engine performance and exhaust emissions. Therefore lower percent of apricot seed kernel oil methyl ester can be used as additive. Anand et al. [50] carried out experiments on a turbocharged, direct injection, multi-cylinder truck diesel engine fitted with mechanical distributor type fuel injection pump using biodiesel–methanol blend and neat karanji oil derived biodiesel under constant speed and varying load conditions without altering injection timings. The results of the experimental investigation indicate that the ignition delay for biodiesel–methanol blend is slightly higher as compared to neat biodiesel and the maximum increase is limited to 1°. CA. Valente et al. [51] investigate the impacts on fuel consumption and exhaust emissions of a diesel power generator operating with biodiesel. The results showed increased fuel consumption with higher biodiesel concentration in the fuel. Moon et al. [52] perform an experimental study was conducted on a 2.0 L 4 cylinders turbocharged diesel engine fuelled with those alternative diesel fuels to investigate the engine-out emission characteristics under various steady-state engine operating conditions. The results revealed that noticeable decreases in THC (22–56%) and CO (16–52%) emissions for GTL–biodiesel blends were observed, whereas NO_x emissions for GTL–biodiesel blends increased by a maximum of 12% compared to diesel. Zhu et al. [53] use ultra low sulphur diesel and two different kinds of biodiesel fuels blended with baseline diesel fuel in 5% and 20% v/v were tested in a Cummins 4BTA direct injection diesel engine, with a turbocharger and an intercooler. Experiments were conducted under five engine loads at two steady speeds (1500 rpm and 2500 rpm). The results indicate that, compared to base diesel fuel, the increase of biodiesel in blends could cause certain increase in both brake specific fuel consumption and brake thermal efficiency. Rajasekar et al. [54] have find out that oxygenated fuels can substantially replace the large demand for diesel to generate power for then industries and to fuel diesel engines of the vehicles. In spite of the many advantages of using them, most of the researchers have reported higher NO_x emissions, which is a deterrent to the market expansion of these fuels. Smith et al. [55] have said biodiesel is widely accepted as an additive for fossil derived diesel in compression ignition engines. It offers many advantages including: higher cetane number; reduced emissions of particulates, NO_x, SO_x, CO, and hydrocarbons; reduced toxicity; improved safety; and lower lifecycle CO_2 emissions. Karavalakis et al. [56] In their present study, studied the effects of different biodiesel blends on the unregulated emissions of a Euro 4 compliant passenger car were

Table 2
Work done by different researchers on engine performance using biodiesel.

Author	Type of oil	Type of engine used	Conclusion
[1]	Biodiesel (with 20% blends)	4276T Turbo Charged Diesel Engine	For the same efficiency the biodiesel blends have more fuel consumption in comparison to diesel
[2]	B-100 and diesel fuel	High speed direct injection diesel engine	At low temperature combustion CO and HC pollutant emission are reduced with the use of biodiesel
[3]	Biodiesel from cotton seed oil	Diesel engine	Exhaust emission of CO and particulate matter and smoke emission were reduced slight increase in NO_x emission. Thermal efficiency with biodiesel is less (slightly) than neat diesel fuel due to lower heating value.
[5]	Biodiesel and diesel	Marine craft diesel engine	For the same efficiency the fuel consumption is higher in case of biodiesel and CO emission will be lower when engine runs at high speed
[6]	Soy and yellow grease derived biodiesel and ultra low sulphur diesel fuel	Single-cylinder horizontal type diesel engine	NO_x emissions are higher for biodiesel. Soot, CO, unburnt hydrocarbon emission were lower for biodiesel engine.
[7].	Biodiesel/diesel	Diesel engine (during MVEG-A cycle) under road condition	Biodiesel can be used safely in Diesel engine at least in smaller blending ratio. Higher NO_x emission CO and HC emission are reduced
[8].	Aviation fuel/JP-5/biodiesel/diesel	Single cylinder stationery diesel engine	JP-5 reduces both NO_x and particulate emission. Biodiesel reduce particulate emission Diesel have large emission as compared to biodiesel and JP-5
[11]	Diesel B-20 B-80 BE-20(20% ethanol)	CI Engine	Engine performance was improved with the use of BE-20 and exhaust emission were fairly reduced.
[12]	Biodiesel with 10% blended methanol or 10% fumigation methanol/Diesel fuel	4 Cylinder Direct injection Diesel engine at constant speed of 1800 rpm	Reduction in CO_2, NO_x and particulate emission and reduction in mean particle diameter. For the blended mode there is slightly higher break thermal efficiency at low engine load while fumigation mode gives High break thermal efficiency at medium and high temperature load.
[13]	Waste cooking Biodiesel fuel/Diesel	Direct Injection engine water cooled 2 cylinder in line, naturally aspirated RD-270	Sulphur content of biodiesel fuel is 180 ppm which is 28 times lesser than existing diesel fuel Maximum power and torque using Diesel fuel are 18.2 kW and 64.2 Nm at 3200 rpm and 2400 rpm respectively. By using biodiesel power is increased by 2.7% and torque is increased by2.9%
[16]	Diesel oil B-5 B-20 (biodiesel made of rape seed oil)	Diesel engine	The result indicate the use of biodiesel results lower smoke capacity by 60% and higher BSFC up to 11%compared to diesel fuel
[26]	Fuel blend containing 5%, 20%, 35%, 50% of soybean biodiesel in diesel oil. Fuel blend containing 5%, 20%, 35%, 50% of castor biodiesel in diesel oil	Diesel engine with varying load from 9.6 to 37.5 kW	Increase in fuel consumption with higher biodiesel concentration in fuel. Soybean biodiesel show less concentration than castor biodiesel blend at a given temperature.
[27]	Biodiesel (10% blend)	Common rail diesel engine	Particulate emissions were reduced. Marginal effect on NO_x emission
[28]	Anhydrous ethanol diesel fuel biodiesel (B-100) natural gas	Internal combustion engine	The most polluting fuel is diesel ecological efficiency for B-100 is 86.75%, natural gas 91.95%, ethanol 82.52%, diesel 77.34%
[30]	Diesel fuel and biodiesel fuel	Single cylinder diesel engine with EGR	CO and smoke emission were reduced by using biodiesel and NO_x emission were reduced when EGR is applied
[33]	Diesel fuel and biodiesel fuel	4 Cylinder turbocharged Diesel engine at 1400 rpm speed	Significant reduction in particulate matter, CO and unburnt HC NO_x emission increased by 11.2%. Biodiesel had 13.8% increase in BSFC
[34]	Diesel fuel and biodiesel fuel	Outboard diesel engine	CO emission reduce by 12% NO_x emission increased by 20% Increase in BSFC by 11.4%

examined. Two fresh and two oxidized biodiesel fuels of different source materials were blended with an ultra low sulphur automotive diesel fuel at proportions of 10, 20, and 30% v/v. Hoon and Gan [57], in this work, levels of exhaust species from the combustion of palm oil methyl ester (POME) and its blends with No. 2 diesel in a non-pressurised, water-cooled combustion chamber are evaluated. Ozsezen and Canakci [58] studied the exhaust emissions of an unmodified diesel engine fuelled with methyl ester of waste frying palm-oil (biodiesel) and its blends with petroleum based diesel fuel (PBDF) were investigated at the full load-variable speed condition. The results showed that when biodiesel was used in the test engine, the fuel line pressure increased while air fuel equivalence ratio and ignition delay decreased. Yehliu et al. [59] comparing conventional, synthetic and vegetable oil-derived diesel fuels and by comparing a single pulse injection and a split (pilot and main) injection process. Gill et al. [60] give the overview of Gas-to-Liquid (GTL), Biomass-to-Liquid (BTL) and Coal-to- Liquid (CTL) theory and technology by the use of FischereTropsch (F–T) processes. Sayin [61] studied the effects of methanol–diesel (M5, M10) and ethanol–diesel (E5, E10) fuel blends on the performance and exhaust emissions were experimentally investigated. The results showed that brake specific fuel consumption and emissions of nitrogen oxides increased while brake thermal efficiency, smoke opacity, emissions of carbon monoxide and total hydrocarbon decreased with methanol–diesel and ethanol–diesel fuel blends. Perez et al. [62] a single-cylinder, naturally aspirated, air-cooled, direct-injected diesel engine was used to study the effects of oxygen enrichment of intake air on engine performance at simulated high altitude conditions. It was found that power output depended mainly on engine load and was not improved by the use of oxygen-enriched air, but it did not decrease significantly for altitudes up to 2600 m (8500 ft). Rehman et al. [63] the results of an ongoing development program aimed at determining the technical feasibility of utilizing biodiesel in IS/60 Rovers gas turbine. The test rig is equipped with a dynamometer for turbine loading and AVL exhaust gas analyzer has been used to record emissions. The results compared with the base line performance using diesel fuel under normal conditions show encouraging outcomes. Magnusson and Nilsson [64] uses a spark-ignited two-stroke chainsaw engine was used to study the influence of pure oxygenated fuels on exhaust emissions of carbonyls (aldehydes and

ketones) and regulated emissions, i.e. hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_x). Oner and Altun [65] use a substitute fuel for diesel engines was produced from inedible animal tallow and its usability was investigated as pure biodiesel and its blends with petroleum diesel fuel in a diesel engine. Radu et al. [66] use of a biodiesel type fuel in D.I. Diesel engine; the fuel injection system and the engine were tested. The results indicated that the injection characteristics are affected when a blend containing 50% methyl ester and 50% petrodiesel is used as fuel (injection duration, pressure wave propagation time, average injection rate, peak injection pressure). He et al. [67] studied the characteristics of carbonyl compounds emissions on a direct injection, turbocharged diesel engine fuelled with pure biodiesel derived from soybean oil. Cheung et al. [68] perform experiments and it is carried out on a diesel engine operating on Euro V diesel fuel, pure biodiesel and biodiesel blended with methanol. The blended fuels could lead to higher CO and HC emissions than biodiesel, higher CO emission but lower HC emission than the diesel fuel. There are simultaneous reductions of NO_x and PM to a level below those of the diesel fuel. Guarieiro et al. [69] state that impact of vehicular emissions on air depends, among other factors, on the composition of fuel and the technology used to build the engines. Ganapathy et al. [70] proposes a methodology for thermodynamic model analysis of Jatropha biodiesel engine in combination with Taguchi's optimization approach to determine the optimum engine design and operating parameters. Fontaras Georgios et al. [71] Biodiesel use as an automotive fuel is expanding around the world and this calls for better characterization of its impact on diesel combustion, and emissions. Yage et al. [72] Experiments were conducted on a 4-cylinder direct-injection diesel engine using ultra-low sulphur diesel, biodiesel and their blends, to investigate the regulated and unregulated emissions of the engine under five engine loads at an engine speed of 1800 rev/min. The brake specific fuel consumption and the brake thermal efficiency increase. The HC and CO emissions decrease while NO_x and NO_2 emissions increase. Tiegang et al. [73] use an optically accessible single-cylinder high-speed direct-injection (HSDI) diesel engine was used to investigate the spray and combustion processes for biodiesel blends under different injection strategies. The experimental results indicated that the heat release rate was dominated by a premixed combustion pattern and the heat release rate peak became smaller with injection timing retardation. Yage et al. [74], experiments were conducted on a 4-cylinder direct-injection diesel engine using ultralow sulphur diesel blended with biodiesel and ethanol to investigate the gaseous emissions of the engine under five engine loads at the maximum torque engine speed of 1800 rev/min. For the diesel-biodiesel fuels, the brake specific HC and CO emissions decrease while the brake specific NO_x and NO_2 emissions increase. Karavalakis et al. [75] presents the regulated and unregulated exhaust emissions of a diesel passenger vehicle, operated with low sulphur automotive diesel and soy methyl ester blends. Lin et al. [76] uses VOME in an unmodified direct injection (DI) diesel engine yielded a higher brake specific fuel consumption (BSFC) due to the VOME fuel's lower calorific value. Lopez et al. [77] state that due to growing concerns about NO_x and particulate matter (PM) emissions from diesel engines, stricter regulations are being introduced requiring advanced emission control technology. Boudy and Seers [78] presents the influence of biodiesel fuel properties on the injection mass flow rate of a diesel common-rail injection system. Wu et al. [79] study the performance of five methyl esters with different sources was studied: cottonseed methyl ester (CME), soybean methyl ester (SME), rapeseed methyl ester (RME), palm oil methyl ester (PME) and waste cooking oil methyl ester (WME). Total particulate matter (PM), dry soot (DS), non-soot fraction (NSF), nitrogen oxide (NO_x), unburned hydrocarbon (HC), and carbon monoxide (CO) were investigated on a Cummins ISBe6 Euro III diesel engine and compared with a baseline diesel fuel. Results show that using different methyl esters results in large PM reductions ranging from 53% to 69%, which include the DS reduction ranging from 79% to 83%. Both oxygen content and viscosity could influence the DS emission. Higher oxygen content leads to less DS at high load while lower viscosity results in less DS at low load. NSF decreases consistently as cetane number increases except for PME. The cetane number could be responsible for the large NSF difference between different methyl esters. Saleh [80] Jojoba methyl ester (JME) has been used as a renewable fuel in numerous studies evaluating its potential use in diesel engines. These studies showed that this fuel is a very good gas oil substitute but an increase in the nitrogenous oxides emissions was observed at all operating conditions. Saleh [81] JME fuel in a fully instrumented, two-cylinder, naturally aspirated, four-stroke direct injection diesel engine. The results showed that EGR is an effective technique for reducing NO_x emissions with JME fuel especially in light-duty diesel engines. With the application of the EGR method, the CO and HC concentration in the engine-out emissions increased. Haldar et al. [82] used 10%, 20%, 30% and 40% blends of degummed non-edible oils and diesel are used in a Ricardo variable compression engine and compare the performance and emission characteristics. It is observed that the non-edible oil of Jatropha gives the best results related to the performance and emissions at high loads and 45° bTDC injection timing. Haldar et al. [83] used a non-edible vegetable oil in diesel engine for its fuel properties which are comparable with diesel. Blends (10%, 20%, 30%, and 40% v/v) of pure Putranjiva oil and diesel are used in Ricardo Peng et al. [84] used engines (Mitsubishi 4M40-2AT1) with four cylinders, a total displacement of 2.84 L, maximum horsepower of 80.9 kW at 3700 rpm, and maximum torque of 217.6 Nm at 2000 rpm, were mounted and operated on a Schenck DyNAS 335 dynamometer.

Utlu et al. [85] usage of methyl ester obtained from waste frying oil (WFO) is examined as an experimental material. A reactor was designed and installed for production of methyl ester from this kind of oil. Lin et al. [86] used five test fuels in his work to study the particle size distribution: D100 (premium diesel fuel), B100 (100% palmbiodiesel), B20 (20 vol% palm-biodiesel + 80 vol% D100), BP9505 (95 vol% paraffinic fuel + 5 vol% palm-biodiesel) and BP8020 (80 vol% paraffinic fuel + 20 vol% palm-biodiesel). Correa et al. [87] seven carbonyl emissions (formaldehyde, acetaldehyde, acrolein, acetone, propionaldehyde, butyraldehyde, and benzaldehyde) were evaluated by a heavy-duty diesel engine fuelled with pure diesel (D) and biodiesel blends (v/v) of 2% (B2), 5% (B5), 10% (B10), and 20% (B20). Sharma et al. [88] biodiesel is affected by molar ratio, moisture and water content, reaction temperature, stirring, specific gravity. Jha et al. [89] while biodiesel reduces emissions of CO, life cycle CO_2, SO_x, volatile organic compounds (VOC) and particulate matter (PM) significantly, the propensity for the production of NO_x is an important problem that requires extensive research. Xin et al. [90] evaluated oxidation stability of biodiesel, biodiesel produced by alkali-catalyzed method was exposed to supercritical methanol at several temperatures for 30 min. As a result, it was found that the tocopherol in biodiesel is not stable at a temperature higher than 300 °C. Xiaoyan et al. [91], in this study, the efforts to reduce NO_x and particulate matter (PM) emissions from a diesel engine using both ethanol-selective catalytic reduction (SCR) of NO_x over an Ag/Al2O3 catalyst and a biodiesel–ethanol–diesel fuel blend (BE-diesel) on an engine bench test are discussed.

Altun et al. [92], the use of vegetable oils as a fuel in diesel engines causes some problems due to their high viscosity compared with conventional diesel fuel. The experimental results show that the engine power and torque of the mixture of sesame oil diesel fuel are close to the values obtained from diesel fuel and the amounts of exhaust emissions are lower than those of diesel fuel. Tsolakis et al. [93] uses two alternative fuels, biodiesel and bioethanol, in internal combustion engines. Dzida and Prusakiewicz [94] three

commercial fuels were studied: biodiesel (based mainly of the fatty acids methyl esters of rapeseed oil), diesel oil Ekodiesel Ultra (standard petroleum diesel oil with sulphur content less than 10 mg/kg), and ON BIO 10 (blend of 20 vol% of biodiesel with 80 vol% of standard petroleum diesel oil with sulphur content less than 10 mg/kg). Mbarawa [95] the performance, emission and economic evaluation of using the clove stem oil (CSO)–diesel blended fuels as alternative fuels for diesel engine have been carried out. Experiments were performed to evaluate the impact of the CSO–diesel blended fuels on the engine performance and emissions. Cheng et al. [96] Experiments were conducted on a 4-cylinder direct-injection diesel engine with fumigation methanol injected into the air intake of each cylinder. Saydut et al. [97] sesame (Sesamum indicum L.) oil was extracted from the seeds of the sesame that grows in Diyarbakir, SE Anatolia of Turkey. Sesame seed oil was obtained in 58 wt/wt%, by traditional solvent extraction. Chen et al. [98] the ethanol blend proportion can be increased to 30% in volume by adding the vegetable methyl ester. Engine performance and emissions characteristics of the fuel blends were investigated on a diesel engine and compared with those of diesel fuel. Experimental results show that the torque of the engine is decreased by 6–7% for every 10% (by volume) ethanol added to the diesel fuel without modification on the engine. Asad et al. [99], multi-event fuel injection strategies under independently controlled exhaust gas recirculation and intake boost have been applied to produce the heat release patterns that characterize the clean combustion techniques of modern diesel engines.

Kwanchareon et al. [100] the phase diagram of diesel–biodiesel–ethanol blends at different purities of ethanol and different temperatures. Fuel properties (such as density, heat of combustion, cetane number, flash point and pour point) of the selected blends and their emissions performance in a diesel engine were examined and compared to those of base diesel. It was found that the fuel properties were close to the standard limit for diesel fuel; however, the flash point of blends containing ethanol was quite different from that of conventional diesel. Base on the above literature a comprehensive table is prepared showing the work done by various researchers on engine performance using biodiesel from different sources as the engine fuel (Table 2).

3. Conclusion

This review work shows that in recent years, biodiesel has been in focus as a part replacement Component of petroleum diesel. The reasons for this focus are obvious as most countries of the world are exploring alternate energy sources, which are environment friendly and are from renewable sources. Bio-diesel scores very well as an alternate fuel of choice as it helps in decreasing dependence on fossil – fuels and also as it has almost no sulphur. Higher cetane of biodiesel as compared to petro diesel implies its much improved combustion profile in an internal combustion engine. The pollutant component from exhaust are also decreased by using biodiesel Because of the well-established advantages of biodiesel, its production capacities world over has witnessed a double-digit annual growth rate for the last few years. So the focus of work from onward should be development of 100% biodiesel.

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